

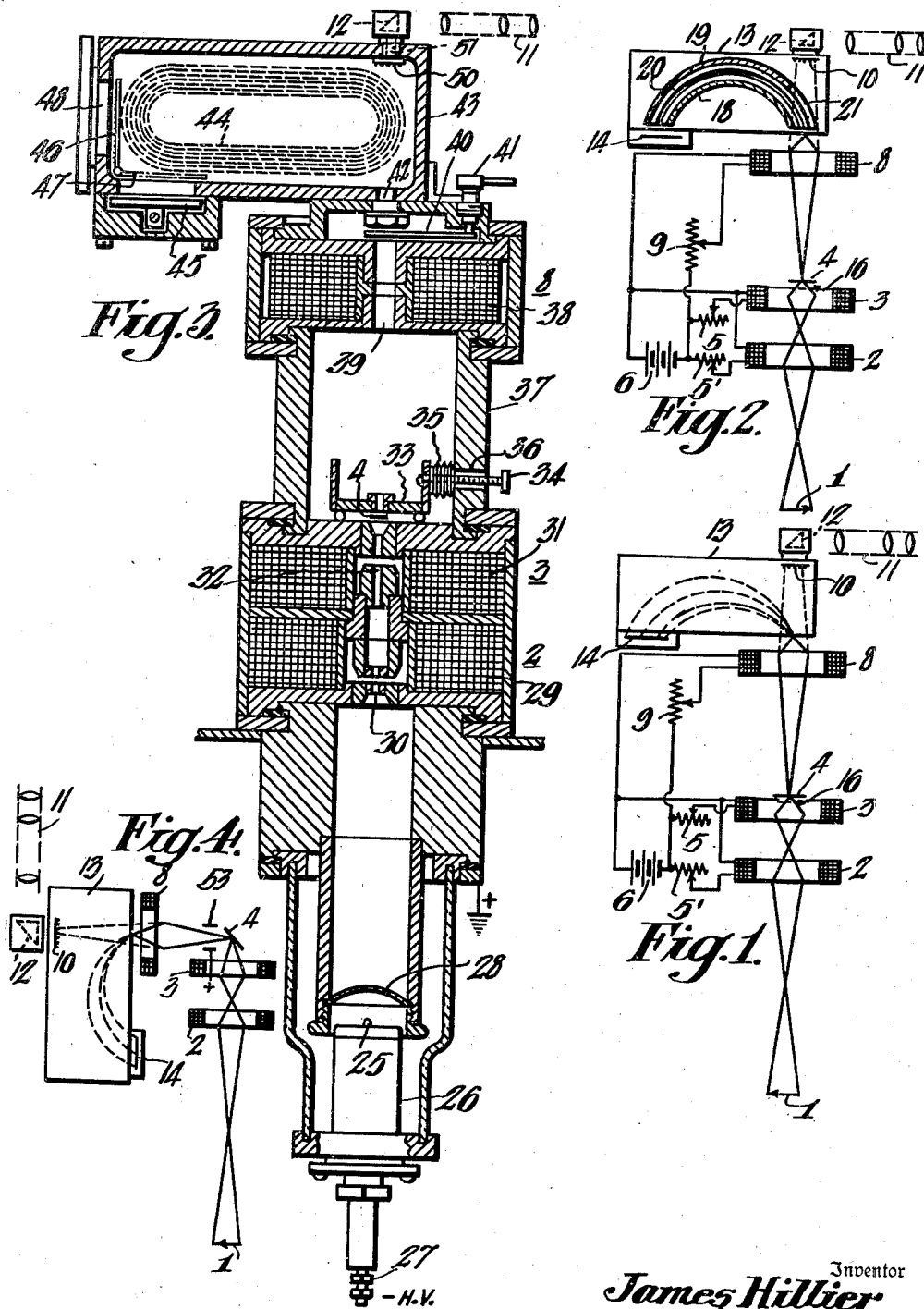
April 1, 1947.

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2,418,228

ELECTRONIC MICROANALYZER

Filed Oct. 8, 1943



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UNITED STATES PATENT OFFICE

2,418,228

ELECTRONIC MICROANALYZER

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Application October 8, 1943, Serial No. 505,572

22 Claims. (Cl. 250—49.5)

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This invention relates generally to electron optics and more particularly to an improved method of and means for microanalyzing materials by electron irradiation.

Briefly, two embodiments of the invention contemplate the generation of an electron probe, having extremely minute cross-sectional area, which is focused upon a minute area of the electron permeable material to be analyzed. Electrons which are transmitted, or modified, or reflected from the material by the impinging electrons, are subjected to an electrical or magnetic deflecting field which deflects the electrons as a function of their velocities. The deflected electrons impinge upon a fluorescent screen for visual observation of the electron velocity distribution pattern, or impinge upon a photographic plate for providing a permanent record of the pattern. Means are included for observing upon an auxiliary fluorescent screen the portion of the specimen upon which the electron probe impinges. Means also are provided for adjusting the position of the material under observation with respect to the axis of the electron probe.

The operation of the electronic microanalyzer is based on the fact that when electrons pass through matter some of the energy of the electrons is transformed into X-ray radiation energy. Since this transformation of energy must take place according to the rules of quantum theory, it can easily be seen that for an electron to excite a photon of the characteristic X-ray radiation of an element it must lose energy in an amount equal to or greater than that contained in the X-ray photon. Thus among the electrons leaving a specimen containing a certain element there will be a predominance of those electrons which have lost an amount of energy equal to or slightly greater than the energy contained in a single photon of the characteristic X-ray radiation of that element. The velocity spectrum of the electrons leaving a point of the specimen will have "lines" corresponding to the important X-ray lines of all the elements contained in the area of the specimen being examined. Electron microanalysis offers several advantages over ordinary methods of microanalysis. Submicroscopic regions of a specimen can be analyzed without removing the region from the specimen, or without changing it in any way. By means of the electron microscope associated with the analyzer, the area of the specimen analyzed can be observed before and after analysis, so that the relationship of the region examined to the remainder of the specimen can be determined.

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The apparatus required for electronically analyzing materials is similar in many respects to the conventional electron microscope. The principal difference resides in the fact that electrons which penetrate the substance under observation are subjected to deflecting electric or magnetic fields whereby they are deflected amounts proportional to their velocities before impingement upon the observation screen. In accordance with the teachings of the instant invention, a relatively simple attachment may be provided for conventional electron microscopes to permit microanalysis by electronic methods.

Another embodiment of the invention may be employed to analyze electronically the characteristics of substances substantially opaque to electron irradiation. According to this embodiment of the invention, a minute area of the electron opaque substance is irradiated by the electron probe, and the reflected electron beam derived from the irradiated area is subjected to the deflecting field and velocity analyzed as described heretofore.

Another modification of the invention contemplates discarding the principal or direct portions of the electrons transmitted or reflected by the specimen, and applying only electrons derived from the specimen at some predetermined angular relation thereto to the effects of the uniform field for velocity analysis thereof.

Among the objects of the invention are to provide an improved method of and means for microanalyzing materials permeable to electron irradiation. Another object of the invention is to provide an improved method of and means for electronically analyzing minute specimens of materials. A further object of the invention is to provide an improved method of and means for electronically analyzing materials by subjecting a minute area of the material to electron irradiation, subjecting electrons derived from said irradiated area to the effects of a deflecting field, and indicating the relative velocities of the electrons subjected to said field. Another object is to provide improved means for securing a permanent record of the relative velocities of said electrons subjected to said deflecting field. A still further object includes an improved method of and means for subjecting a minute area of a substance to electron irradiation, subjecting electrons transmitted by said substance to a uniform magnetic field, and indicating the relative velocities of electrons subjected to said magnetic field.

Further objects of the invention include an improved method of and means for electronically

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microanalyzing materials substantially opaque to electron irradiation by irradiating a minute area of said material, selecting at least a portion of the electrons reflected from said material, subjecting said selected electrons to a deflecting field, and indicating the relative velocities of said electrons subjected to said field.

The invention will be further described by reference to the accompanying drawing of which Figure 1 is a schematic diagram of one embodiment thereof, Figure 2 is a schematic diagram of a second embodiment thereof, Figure 3 is a cross-sectional elevational view of a preferred embodiment of the invention according to the schematic diagram of Figure 1, and Figure 4 is a schematic diagram of a third embodiment of the invention. Similar reference characters are applied to similar elements throughout the drawing.

Referring to Figure 1, an electron source 1, which may be provided by a conventional thermionic cathode which is maintained at a relatively high negative potential with respect to an apertured anode electrode, neither of which are shown herein, is imaged by a pair of electron lenses 2, 3 respectively, to irradiate an extremely minute area of an electron permeable object 4. The electron lenses 2, 3, respectively, may be of either the electromagnetic or electrostatic types customarily employed in electron optical apparatus such as, for example, electron microscopes. If electromagnetic lenses are employed, as shown in the drawing, the focus of said lenses may be adjusted by means of series resistors 5, 5' connected between one terminal of each of the magnetic lenses and an energizing current source such as, for example, a battery 6.

A third electron lens 8, which may be energized through a third variable resistor 9 from the battery 6, is disposed coaxially with the first and second electron lenses 2, 3.

The electrons transmitted by the specimen 4 may be selectively subjected to a magnetic field within a deflection chamber 13. The magnetic field will cause the transmitted electrons to follow substantially semi-circular paths and impinge upon an image screen or photographic plate 14. The magnetic field within the deflection chamber 13 will deflect the electrons different amounts determined by their respective velocities whereby a velocity distribution pattern will be provided upon the image screen 14. The focus of the pattern is controlled by varying the current through the third lens 8 by adjusting the resistor 9.

Adjustment of the energizing current applied to the third electron lens 8 will permit observation of the irradiated area of the specimen 4 by effectively transposing the image of the electron source 1 from the specimen 4 to the point indicated by the arrow 16. The highly magnified shadow image of the object 4 thus produced is further magnified and projected on the fluorescent screen, (or photographic plate) at 10, by means of the third lens 8. The image upon the small fluorescent screen 10 may be observed conveniently by means of a conventional light microscope 11 operating, if desired, in conjunction with a prism 12.

It should be understood that the magnetic field within the deflection chamber 13 may be established in any desired manner. It should also be understood that the electron lens system described may be modified in any known manner to provide a suitable electron probe of conven-

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ient cross-sectional area for irradiation of the specimen 4, and that the third electron lens 8 may be omitted entirely if the deflection chamber 13 and image screens 10 and 14 are disposed in close relation with the specimen 4.

Figure 2 is similar in all respects to Figure 1 with the exception that an electric field is substituted for the magnetic field within the deflection chamber 13 of the device of Figure 1 for deflecting the electrons derived from the specimen 4 in accordance with their relative electron velocities. In order to provide relatively long electron paths through an electrostatic field, two arcuate concave electrodes 18, 19, separated by an air gap 20, are disposed in cooperative relation to provide an arcuate tubular electrostatic deflecting element which will cause the deflected electrons to impinge upon the screen 14 to provide a velocity distribution pattern thereon. A small aperture 21 in the wall of the deflecting electrode 19 coincidental with the axis of the electrons derived from the specimen 4 permits a portion of the transmitted electrons to be focused upon the small fluorescent screen 10, when the deflecting electrodes 18, 19 are de-energized, for observation of the electron irradiated area of the specimen 4 by means of an externally disposed light microscope 11 and prism 12, as described heretofore in Figure 1.

Figure 3 is a preferred embodiment of the device described in Figure 1 constructed according to conventional electron microscope practice. The electron source includes a thermionic cathode 25 which is supported by a high potential insulator 26 and connected to a terminal 27 which is maintained at high negative potential. An apertured anode electrode 28, which is maintained at a high positive potential with respect to the thermionic cathode 25, provides an electron beam having relatively high electron velocity. The first electron lens 2 is illustrated as a conventional electromagnetic electron microscope lens including a winding 29 having a pole piece aperture 30. The second electron lens 3 forms a unitary structure with the first electron lens 2 and includes a second winding 31 and a second pole piece aperture 32.

The specimen 4 is supported by a conventional specimen supporting element 33 which may be adjusted with respect to the electron beam axis by an external adjusting knob 34 operating through a conventional bellows joint 35 disposed adjacent an aperture 36 in the outer wall 37 of the supporting structure. The third electron lens 8 may be similar to the first and second electron lenses 2, 3, respectively, and includes a third winding 38 and a relatively large pole piece aperture 39. A shutter 40, operated by an externally controlled knob 41, is interposed between the third electron lens 8 and an aperture 42 in the wall of a deflection chamber 43 which is secured to the supporting structure of the third electron lens.

A magnetic winding 44, disposed external to the deflection chamber 43, provides a magnetic field therein for deflecting electrons entering the aperture 42 and for causing them to impinge upon a photographic plate 45 for providing a permanent record of the deflected electron pattern. The photographic plate 45 may be removed from the deflection chamber 43 by means of an air lock or any other structure customarily employed in conventional electron microscopes. A hinged fluorescent screen 46, pivoted adjacent one edge of the photographic plate 45, may be rotated to

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cover the plate 45 for providing a visual image of the electron velocity distribution pattern. The visual image on the fluorescent screen, when in position 47, shown in dash lines, may be observed through a window 48 adjacent to and normal therewith.

When the winding 44 is de-energized the electron beam entering the deflection chamber 43 through the aperture 42 is projected by the third electron lens 8 upon a small auxiliary fluorescent screen 50. The small auxiliary fluorescent screen 50 may be observed conveniently by means of the external prism 12 and the light microscope 11 disposed adjacent a convenient viewing aperture 51 in back of the small fluorescent screen 50.

The shutter 40 is opened by the shutter adjusting knob 41 to permit observation of the electron irradiated area of the specimen 4 upon the auxiliary viewing screen 50. When the magnetic field is established within the deflection chamber 43 by energization of the magnetic winding 44, the velocity distribution pattern may be observed through the window 48 upon the hinged fluorescent screen 46 when it is in the position indicated by the dash lines 47. The shutter 40 may then be closed to prevent electrons entering through the aperture 42 and the fluorescent screen 46 rotated to its vertical position, as indicated in the drawing. The shutter 40 may then be opened for a desired interval to expose the photographic plate 45.

Figure 4 shows a modification of the invention described in Figures 1 and 3 wherein electron velocity distribution measurements may be made upon specimens which are substantially opaque to electron irradiation. The electron source 1 is focused by the electron lenses 2, 3, respectively, to electron irradiate a minute area of the surface of the specimen 4. The electron irradiation of the specimen 4 will provide secondary electrons having relatively low velocity, and a reflected electron beam having relatively high velocity electrons. The low velocity secondary electrons derived from the specimen 4 are accumulated by a collector electrode 53, while the relatively high velocity reflected electrons are introduced into the deflection chamber 13 and subjected to the deflecting magnetic field for providing a velocity distribution pattern upon the image screen 14.

It should be understood that the angle of incidence of the irradiating electron beam may be varied by rotating the specimen 4 with respect to the electron beam axis. It also should be understood that the low and high velocity electrons derived from the electron irradiating specimen may be separated by any other means known in the art. Similarly, the modification of the invention disclosed in Figure 4 may be adapted readily to the device described in Figure 2 by substituting the electrostatic deflecting field for the electromagnetic deflecting field of the device of Figure 1.

Thus the invention described comprises several modifications of an improved method of and means for microanalyzing materials by electron irradiation.

I claim as my invention:

1. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said

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irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

2. An electron microanalyzer including electron beam generating means and electron beam focusing means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

3. An electron microanalyzer including electron beam generating means and electron beam focusing means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive photographic screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

4. Apparatus of the type described in claim 1 including means disposed adjacent to said deflecting means selectively providing a visual image of said screen.

5. Apparatus of the type described in claim 2 including a fluorescent screen, and means for imaging said object on said fluorescent screen for observing said electron probe irradiation of said object.

6. Apparatus of the type described in claim 2 including a fluorescent screen, and electron beam focus adjusting means for selectively imaging said object on said fluorescent screen for observing said electron probe irradiation of said object.

7. Apparatus of the type described in claim 2 including a fluorescent screen, means for selectively imaging said object on said fluorescent screen for observing said electron probe irradiation of said object, and means for optically magnifying said image on said fluorescent screen.

8. Apparatus of the type described in claim 2 including externally adjustable means for orienting said object with respect to said electron probe.

9. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for support-

ing an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

10. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a magnetic field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

11. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing an electrostatic field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

12. Apparatus of the type described in claim 2 including an externally operable shutter interposed between said object supporting means and said screen for controlling the electron exposure time for said screen.

13. The method of electron microanalyzing a material comprising generating an electron probe of minute cross-sectional area, electron irradiating said material by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, subjecting said electrons derived from said object to a field to deflect said electrons derived from said object as a function of electron velocity, and indicating the relative velocities of said derived electrons.

14. The method of electron microanalyzing a material comprising electron irradiating a minute cross-sectional area of said material to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and

electrons of the inner atomic orbits of said specimen, and indicating the relative velocities of said electrons derived from said area of said material in response to said irradiation.

15. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons from said object, and means interposed between said screen and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide an image on said screen characteristic in shape of the velocity distribution of said electrons impinging thereon.

16. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially opaque to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive screen responsive to said electrons reflected from said object, means for collecting secondary electrons derived from said object in response to said irradiation, and means interposed between said screen and said object means providing a field for deflecting said reflected electrons as a function of their velocity.

17. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive device responsive to said electrons from said object, and means interposed between said device and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide indications on said device characteristic of the velocity distribution of said electrons impinging thereon.

18. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for supporting an object substantially permeable to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive device responsive to said electrons from said object, and means interposed between said device and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide indications on said device characteristic of the velocity distribution of said electrons impinging thereon.

19. An electron microanalyzer including means for providing an electron probe having extremely minute cross-sectional area, means for support-

ing an object substantially opaque to electron irradiation, means for irradiating said object by said electron probe to derive electrons having velocities proportional to the specific absorption of energy due to inelastic collisions between said irradiating electrons and electrons of the inner atomic orbits of said specimen, an electron sensitive device responsive to said electrons from said object, and means interposed between said device and said object means providing a field for deflecting said electrons derived from said object as a function of their velocity to provide indications on said device characteristic of the velocity distribution of said electrons impinging thereon.

20. Apparatus for determining the atomic composition of a predetermined microscopic area of a microspecimen comprising means for electron irradiating said specimen area, and means for indicating the specific absorption of energy due to inelastic collisions between said incident irradiating electrons and electrons of the inner atomic orbits of said specimen.

21. The method of determining the atomic composition of a predetermined microscopic area of a specimen comprising the steps of electron

irradiating said predetermined area of said specimen, and indicating the specific absorption of energy due to inelastic collisions between said incident irradiating electrons and electrons of the inner atomic orbits of said specimen.

22. Apparatus according to claim 3 including means for focusing said electrons derived from said object at a point within said deflecting field.

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